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Aluminum Die Cast Alloy Having High Manganese Content

Field of the Invention

The present invention relates to an aluminum based alloys having substantially improved mechanical and casting properties, and a method for making die cast products from the alloys. More particularly the improved aluminum based alloys comprise 1.0 - 2.0% by weight manganese and a maximum of .6% by weight iron.

Background and Summary of the Invention

The manufacturing industry, and particularly the automotive industry, has increasingly been replacing ferrous materials with light weight materials such as aluminum. The demand for substitute light weight materials has led to the development of aluminum alloys capable of forming structures that will withstand stresses typically reserved for structures formed from ferrous metals. In addition to enhanced strength (including both high yield strength and high elongation values) an aluminum alloy should be die-castable, corrosion resistant, and readily machinable.

Historically, aluminum castings have been characterized by relatively low strength and ductility compared to wrought products of similar compositions. This low strength and ductility is due to the presence of defects in cast alloys which are largely eliminated by mechanical working in wrought alloys. These defects are chiefly of two types: voids due to shrinkage or gas inclusions, and rather large brittle particles due to inter-metallic phases formed from impurity elements or oxide inclusions trapped in the casting during solidification. The development of higher quality castings results from changes in alloy composition and casting techniques designed to minimize the number and size of these defects.

The highest quality aluminum casting alloys, in most part, fall into the Aluminum/Silicon/Magnesium (Al-Si-Mg) type of alloy. Enhanced strength and ductility is achieved chiefly by using high purity input (low iron content and/or modification of $AlSiFe_5$ by Beryllium (Be) additions) as well as keeping the alloy clean. As a consequence of these changes, properties of certain presently available

aluminum castings can approach those of wrought products of equivalent composition.

Aluminum alloys have been developed recently which exhibit enhanced mechanical properties. Such an enhanced aluminum alloy is disclosed in U.S. Patent No. 5,573,606 issued November 12, 1996 to Evans et al. the disclosure of which is expressly incorporated herein by reference. The aluminum based alloy disclosed in Evans et al. exhibits improved yield strength and elongation values over previously available aluminum alloys.

In die casting operations alloys are cast in molds which are commonly made from steel. Aluminum and steel form an inter-metallic compound when brought into contact under appropriate conditions, such as at high temperature. Therefore, components die cast from enhanced aluminum alloys, or from any aluminum alloy, may exhibit "die soldering" or the tendency of aluminum alloys to interact with the steel die to form inter-metallic compounds which bind to the mold, inhibiting removal of the cast component from the mold. Iron is added to aluminum alloys used in casting operations to reduce die soldering. Concentrations of iron above 0.7% by weight are typical in aluminum alloys used in die casting operations. Iron however reduces the ductility of the alloy significantly and decreases the corrosion resistance of the alloy. Therefore, die casters would welcome an aluminum alloy with a low iron content and enhanced mechanical and casting properties. The aluminum based alloy of the present invention contains low iron concentrations, higher manganese concentrations and is less prone to die soldering.

The effects of various elements on the mechanical properties of aluminum alloys have been studied, however, the investigations have been conducted mostly on relatively simple systems, binary or ternary alloys. Most commercial aluminum die casting alloys are complex alloy systems containing several alloy and impurity elements. The large number of elements encountered in these alloys, their low, varying concentrations and the possibility of interactions between the alloy elements, makes the systematic study of the effect of the individual elements on the properties of commercial alloys very complicated and difficult. Regardless of the difficulty in deciphering the effects individual elements have on an alloy's mechanical properties, iron, manganese, magnesium, copper, silicon, titanium and beryllium are

accepted by skilled practitioners as having the following general effects on aluminum alloy properties:

Iron is typically added to die casting aluminum alloys for the purpose of preventing the aluminum alloy from sticking to a metal die during the course of the die casting operation ("die soldering") and enhancing the release of the aluminum alloy from the die. However, the addition of iron lowers the elongation of the aluminum alloy.

Manganese is added to aluminum alloys for the purpose of eliminating the adverse effect of the addition of iron. It has been believed that the percent by weight of manganese should seldom exceed one half of the percent by weight of iron in an aluminum alloy because an excess of manganese would result in a substantial lowering of the mechanical strength of the aluminum alloy.

Magnesium is typically incorporated to enhance the tensile strength of the alloy. Al-Mg binary alloys have high strength, excellent corrosion resistance, weldability and surface finish. However, while increased magnesium content enhances the hardness and fatigue resistance of the alloy, it also decreases the alloy's ductility. An additional reason for limiting magnesium content in the alloy is that magnesium can easily oxidize to form magnesium oxide (MgO) micro-sized particles within the melt. At high holding temperatures (greater than 750°C) spinel, which is a complex octahedral aluminum magnesium oxide crystal, usually forms and grows rapidly forming inclusions in the melt. These inclusions reduce the fluidity and elongation properties of the alloy.

Copper can also be added to an aluminum alloy to increase the strength of the alloy. As copper content increases, hardness of the alloy increases, but strength and ductility depend on whether the Cu is in solid solution, or as spheroidized and evenly distributed particles. Copper decreases the electrolytic potential, and also the corrosion resistance. Copper bearing alloys tend to pit severely in the annealed condition and when age hardened may be susceptible to intergranular or stress corrosion.

Silicon is an important component of the alloy for the purpose of improving the flowability of the alloy in a molten state during the course of the die casting operation. Al-Si alloys have low shrinkage and narrow freeze range resulting

in their good hot tear resistance, soundness and good weldability. Silicon in Al-Mg alloys reduces ductility and elongation without a compensating increase in strength. The combined introduction of copper and silicon significantly increases the hardness of alloy but sharply reduces the elongation.

Titanium is extensively used to refine the grain structure of aluminum casting alloys, often in combination with smaller amounts of boron. Titanium is often employed in concentrations greater than those required for grain refinement to reduce cracking tendencies in hot shot compositions.

Beryllium is added to Al-Mg based alloys to prevent oxidation of the magnesium content of the aluminum alloy. As little as 0.005% to 0.05% by weight beryllium added to an aluminum based alloy melt causes a protective beryllium oxide film to form on the surface. Without the protection that beryllium provides, significant magnesium losses can occur during casting because magnesium is highly reactive to oxygen. Magnesium oxide by itself does not form a protective barrier to prevent magnesium loss. Beryllium has also been included in aluminum alloys to enhance the corrosion resistance, elongation and strength of aluminum alloys. Therefore in accordance with the current state of the art, beryllium is routinely included in Al-Mg alloys; the percentage of beryllium varying with the magnesium content of the aluminum alloy.

Contrary to the presently accepted teaching regarding the detriments of adding manganese in concentrations greater than one half the concentration of iron, applicants' have discovered that the mechanical properties of a low iron content (below 0.7% by weight) Mg-Si-Al alloy are not substantially affected by increasing the manganese content to between 1.0-2.0% by weight, while the susceptibility of components die cast from such alloy to die soldering is substantially reduced.

Applicants' present invention is directed to a die casting aluminum alloy comprising 1.0 - 2.0% by weight manganese, and a maximum of 0.6% by weight iron. One embodiment of such alloy also includes a maximum of 1.75% by weight magnesium. A second high strength embodiment of such alloy includes 2.5-4.0% by weight magnesium and a maximum of .003% by weight beryllium. These aluminum alloys are useful for forming light weight die cast articles that have superior elongation properties and do not exhibit die soldering.

Detailed Description of the Invention

Previously described die castable aluminum alloys lack the elongation properties and lack of susceptibility to die soldering of the present aluminum compounds.

Applicant's low iron content and high manganese content aluminum alloys are not as susceptible to die soldering as previous low iron content aluminum alloys. Iron is added to aluminum alloys to reduce die soldering and is found to effectively reduce die soldering when present in excess of 0.7% by weight. However aluminum alloys containing iron in excess of 0.7% by weight experience reduced ductility and corrosion resistance. Manganese is added to aluminum alloys to reduce the deleterious effects of iron by combining with the iron to form plate-like structures resembling Chinese script. Manganese is usually controlled in the amount of less than half of the iron content by weight. In the disclosed aluminum alloys, the iron content is limited to less than 0.6% by weight and the manganese content is between 1.0 - 2.0% by weight. It is believed that the increased manganese content acts as a substitute for the reduced iron content to reduce die soldering.

The strength of the present alloys can be increased by increasing their content of magnesium coupled with a beryllium content of less than 0.003% by weight. The technique of incorporating low amounts of magnesium into aluminum alloys to enhance the strength of the alloy is known to those skilled in the art. Increasing the magnesium content beyond 2.5% by weight is reported to decrease the elongation of the alloy. However, applicant's high magnesium content aluminum alloys (2.5 - 4.0% by weight magnesium) have enhanced elongation over presently available die castable aluminum alloys.

Beryllium has been described as an important component of magnesium containing aluminum alloys for its properties of preventing oxidation of magnesium. The inclusion of beryllium was also thought to enhance the mechanical strength of the alloy. In fact, applicant's have discovered that decreasing beryllium content in an aluminum alloy having a high content of magnesium (2.5% to 4% by weight) will increase the elongation of the aluminum alloy. Accordingly, the beryllium-containing aluminum alloy of the present invention has been formulated to have a beryllium content of less than 0.003% by weight. More preferably the

beryllium content is less than 0.0003% by weight and most preferably the beryllium content is zero.

Applicant's invention is directed to an aluminum alloy having 1.0 - 2.0% by weight manganese, and a maximum of 0.6% by weight iron. Applicant's alloys include either less than 1.75% by weight magnesium or 0.001 - 0.003% by weight beryllium. Aluminum alloys in accordance with the present invention also include elements selected from the group consisting of silicon, copper, zinc, nickel, titanium, chromium, tin and lead. The aluminum based die casting alloys of the present invention also include certain unavoidable impurities (including but not limited to calcium, cadmium, gallium and sodium). A preferred high magnesium content embodiment in accordance with the present invention comprises 1.0 - 2.0% by weight manganese, a maximum of 0.6% by weight iron, 2.5 - 4.0% by weight magnesium, a maximum of 0.10% by weight zinc, a maximum of 0.45% by weight silicon, a maximum of 0.10% by weight copper, and less than 0.003% by weight beryllium with the remainder being aluminum.

In one preferred embodiment of the present invention the high magnesium content aluminum alloy comprises 2.5 - 4.0% by weight magnesium, 1.0 - 2.0% by weight manganese, 0.25 - 0.6% by weight iron, 0.2 - 0.45% by weight silicon, less than 0.003% by weight beryllium with the remainder being aluminum. In an alternative embodiment, the high magnesium content aluminum alloy comprises 1.0 - 2.0% by weight manganese, 2.5 - 3.0% by weight magnesium, 0.05 - 0.10% by weight copper, 0.25 - 0.6% by weight iron, 0.2 - 0.45% by weight silicon, less than 0.003% by weight beryllium with the remainder being aluminum.

Applicant has also found that by decreasing the iron content in common aluminum alloys, such as A356, A357, and A206, and increasing the manganese content to 1.0 - 2.0% by weight that there is little or no effect on the tensile strength, yield strength, or elongation percentage while ductility and corrosion resistance are increased and susceptibility to die soldering is decreased. In an additional alternative embodiment the aluminum alloy comprises 1.0 - 2.0% by weight manganese, 0.25 - 0.7% by weight magnesium, a maximum of .20% by weight copper, a maximum of .20% by weight iron, 6.5 - 7.5% by weight silicon, a maximum of 0.20% by weight titanium, and a maximum 0.10% by weight zinc with the

remainder being aluminum. Yet another alternative embodiment of the aluminum alloy comprises 1.0 - 2.0% by weight manganese, 0.15 - 0.350% by weight magnesium, 4.2 - 5.0% by weight copper, a maximum of 0.1% by weight iron, a maximum of 0.05% by weight silicon, 0.15 - 0.2% by weight titanium, and a maximum of 0.1% by weight zinc with the remainder being aluminum.

Applicant's described high magnesium content aluminum alloy has enhanced strength in comparison to currently available die castable aluminum alloys. In particular, applicant's described high magnesium content aluminum alloys provide a novel die casting aluminum alloy having a yield strength greater than or equal to 16 ksi (110. MPa) and an elongation value of greater than or equal to 17%. More preferably the alloy has a yield strength of 17 to 18 ksi (117-124 MPa) and an elongation value of greater than or equal to 20%.

The aluminum alloy of the present invention is prepared using standard procedures known to those of ordinary skill in the art. The present aluminum alloy can be used in standard die casting processes known to those skilled in the art to form a variety of light weight die cast articles. Preferably a vacuum die casting process is used wherein the process involves drawing a vacuum on the mold cavity and the passageways (the runner system including the shot sleeve and transfer tube to the furnace) through which the molten metal is fed to remove air which might otherwise be trapped by the molten metal. The process of using this vacuum system to draw the molten metal into the shot sleeve is referred to as vacuum ladling.

One preferred process for die casting the present aluminum alloy utilizes VERTICAST die cast machines. VERTICAST machines are die cast machines known in the trade for their vertical orientation, particularly an orientation in which the upper and lower molds are carried, respectively, on upper and lower platens to provide a plurality of mold cavities spaced about a vertical center axis with a vertically arranged shot sleeve and injection plunger for forcing the molten metal upwardly into the concentrically arranged mold cavities. However, the aluminum alloy of the present invention can also be cast with equal efficiency on horizontal casting machines that have been modified for vacuum die evacuation ladling. Most preferably the aluminum alloy is cast using the process described in U.S. Patent No. 5,211,216, the disclosure of which is expressly incorporated herein by reference. This

process ensures minimal contact of the alloy with atmospheric oxygen, thus reducing the need for beryllium in the magnesium aluminum alloy to control magnesium oxidation.

The present aluminum alloy can be used to form a variety of motor vehicle parts including but not limited to steering wheels, steering columns, instrument panel and instrument panel braces, seat backs and seat bottoms, airbag modules/cans, wheel rims, and energy absorbing brackets. The alloy is particularly suited for any application having load and impact requirements where properties of high elongation are desirable.

Example 1

Comparison of Al-Mg Alloy Strength with and without increased Mn

Mechanical property tests were conducted using an MTS testing machine. The testing procedure followed the ASTM standard B 557-84, "Standard Methods of Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products". Tensile strength, yield strength, and elongation were measured using a die cast test bar (see Fig. 1). The test bar has an overall length L of 9 inches (22.86 cm) minimum, a reduced section A (2.25 inches (5.715 cm) minimum), a gage length G (2.00 inches (5.08 cm) in length), a diameter D (0.250 inches (6.35 cm) in length) and flat end portions F for hardness testing (1.5 inches (3.81 cm) in length). The distance between grips B is a minimum of 4.5 inches (11.43 cm) and the diameter of the two end sections C is 0.375 inches (0.9525 cm). A chart recorder was used to record and display load-displacement diagram and the data of load vs. displacement were stored in a computer for analysis. The tensile strength (TS) was calculated by dividing the maximum load by the original cross-sectional area of the reduced section of the specimen. The load value at fracture is the maximum load for the specimen. In a testing machine this maximum value is automatically stored in its computer operating system and displayed. The maximum load can also be calculated from the curve of load vs. displacement displayed on the chart or stored in the recording computer. The maximum load stored in the machine's computer operating system was used in the TS calculation. The as-die cast specimens used were not perfectly round; the dimensions of the cross-sectional area slightly varied from specimen to specimen. The maximum

and minimum diameters at the center of the reduced section were measured for each specimen and the average of the maximum and minimum diameters was used as the diameter for determining the original cross sectional area of the specimen.

The elongation is the increase in length of the gage length, expressed as a percentage of the original gage length. The original gage length of 2.0 inches (5.08 cm) was carefully measured and marked. The increase in length of the gage length was determined by carefully fitting the ends of the fractured specimen together and measuring the distance between the gage marks. The elongation can also be calculated based on the curve of load vs. displacement. In this method the increase in length (plastic extension) is estimated by subtracting the elastic extension from the total extension at the fracture. This requires that the curve shows a clear initial straight line, which represents the elastic deformation of the specimen.

Yield strength was determined by the "offset method" at an offset of 0.2%. In this method a straight line is drawn on the stress-strain diagram parallel to the initial straight line on the curve of stress vs. strain. This line is placed at a distance of 0.2% of the length of the reduced section from the initial straight line in the direction of the strain axis. The stress at the point, where the straight line drawn and the stress-strain curve intersect, is the yield strength. In these experiments the load v. displacement curve showed two straight lines at the beginning of loading, and the first line was shorter than the second. In these experiments, the yield strengths were calculated based on the second line, which showed reasonable agreement with specification bars and had a relatively narrow variation.

To determine the effect of increased manganese content on the high magnesium aluminum alloy described in Evans et al. (#2 Alloy) on the ultimate tensile strength (UTS), yield strength (YS) and elongation (elong) of aluminum alloys, high manganese content aluminum alloys having the following % by weight composition were tested and yielded the following results:

	#2 Alloy	Modified Alloy	New Alloy
Mg	2.83	2.75	2.80
Fe	0.25	0.30	0.30
Si	0.20	0.20	0.20
Mn	0.60	0.70	1.00-2.00
Cu	0.07	0.05	0.05
Be	0.003	0.003	0.003
UTS (ksi)	32.5 (224 MPa)	32.7 (225 MPa)	33.0 (227 MPa)
YS (ksi)	17.0 (117 MPa)	18.0 (124 MPa)	18.0 (124 MPa)
Elong (%)	22.5	20.5	20.6
Soldering	occasional	Low	None

The data indicates the presence of as much as 1.0% by weight manganese increases UTS and YS while reducing elongation by less than 10% and eliminating soldering.

Additional Al-Mg compositions were tested to determine if increased levels of manganese by weight could reduce die soldering even when concentrations of iron by weight were reduced. For example it was found that if A356 with a maximum 0.60% by weight iron content and a maximum 0.20% by weight manganese content was die cast that die soldering would occur. However when the manganese content of the A356 alloy was increased above 1.0% by weight, die soldering was not observed.